Recent Results from CDF

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Abstract. We report on the recent heavy-quark results from CDF in Run IIa. We focus on a selection of mature analyses that demonstrate the capabilities of the experiment to extract interesting physics from the data. A few of the results presented have already been submitted for publication and papers are being prepared for most of the others.

INTRODUCTION

Having more than $200\,\mathrm{pb}^{-1}$ of physics data in hand and more on the way, CDF's B physics program is in full swing. The triggers for B physics were enhanced in the upgrade for Run II adding the ability to trigger on J/ψ's down to $p_T = 0$, and the ability to trigger on high p_T tracks with significant impact parameter to the beam spot (displaced tracks). Now, in addition to the topics accessible with leptonic or semi-leptonic triggers, analyses that require fully hadronic charm and beauty decays are possible with data selected by the displaced track trigger. Early exploitation of this data resulted in the first three Run II physics papers, measurement of the D_s^+ - D^+ mass difference[1], measurements of charm production cross sections[2], and an improved limit on the rare decay $D^0 \to \mu^+\mu^-$[3].

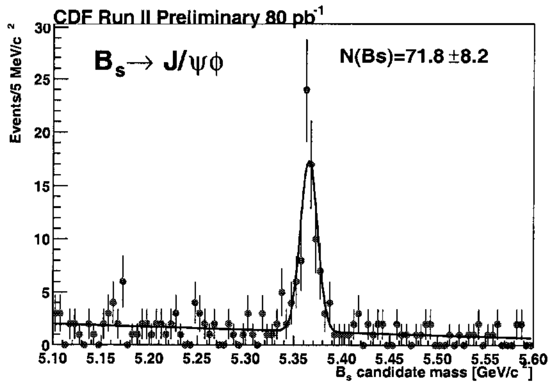

FIGURE 1. Invariant mass distribution for $J/\psi\phi$ combinations where $J/\psi \to \mu^+\mu^-$ is used to trigger the event, and $\phi \to K^+K^-$.

B HADRON MASSES AND LIFETIMES

Measurements of b hadron masses and lifetimes are a prelude to CP measurements in B decays. We use exclusive J/ψ decay modes which give us good signal statistics and little background: $B_d^0 \to J/\psi K^{0*}$, $B^+ \to J/\psi K^+$, $B_s^0 \to J/\psi\phi$, and $\Lambda_b \to J/\psi\Lambda$. The results are summarized in Table 1. The B_s^0 (Fig. 1) and Λ_b (Fig. 2) measurements are the world's best. The B_d^0 and B^+ mass measurements are competitive with the best measurements available.

Lifetime measurements were performed for the same set of decays. The proper time distributions for B_s^0 and Λ_b are shown in Figures 3 and 4, respectively, and the extracted lifetimes are reported in Table 1. These results are competitive with the LEP results, and will improve with additional data. The results for the B_d^0 and B^+ lifetimes

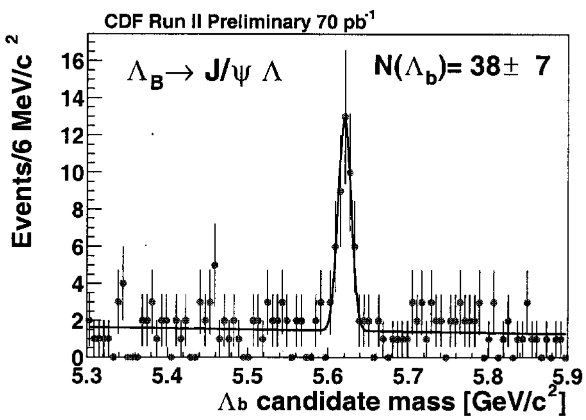

FIGURE 2. Invariant mass distribution for $J/\psi\Lambda$ combinations where $J/\psi \to \mu^+\mu^-$ is used to trigger the event, and $\Lambda \to p\pi^-$.

TABLE 1. Summary of CDF measurements of B masses and lifetimes. The first error is statistical and the second systematic. The B_d an B^+ lifetime results agree within errors with the precise measurements of BaBar and BELLE. The amount of data used varies by analysis.

	mass (MeV)	lifetime (ps)
B_d^0	$5280.30 \pm 0.92 \pm 0.96$	$1.51 \pm 0.06 \pm 0.02$
B^+	$5279.32 \pm 0.68 \pm 0.94$	$1.63 \pm 0.05 \pm 0.04$
B_s^0	$5365.50 \pm 1.29 \pm 0.94$	$1.33 \pm 0.14 \pm 0.02$
Λ_b	$5620.4 \pm 1.6 \pm 1.2$	$1.25 \pm 0.26 \pm 0.10$

are consistent with the precise measurements of BaBar and BELLE. Additional details about lifetime measurements were presented by D. Zieminska[4].

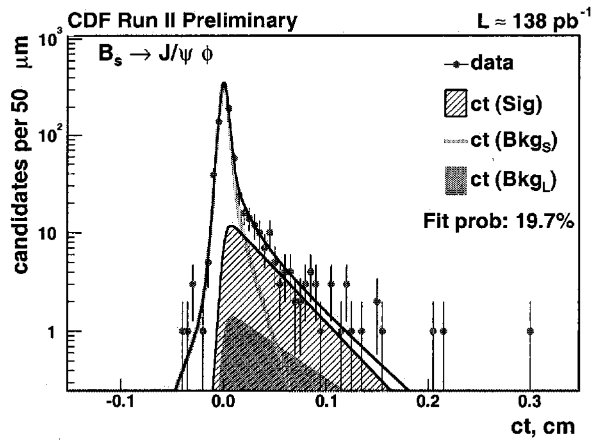

FIGURE 3. Proper time distribution for $J/\psi\phi$ combinations where $J/\psi \to \mu^+\mu^-$ is used to trigger the event, and $\phi \to K^+K^-$.

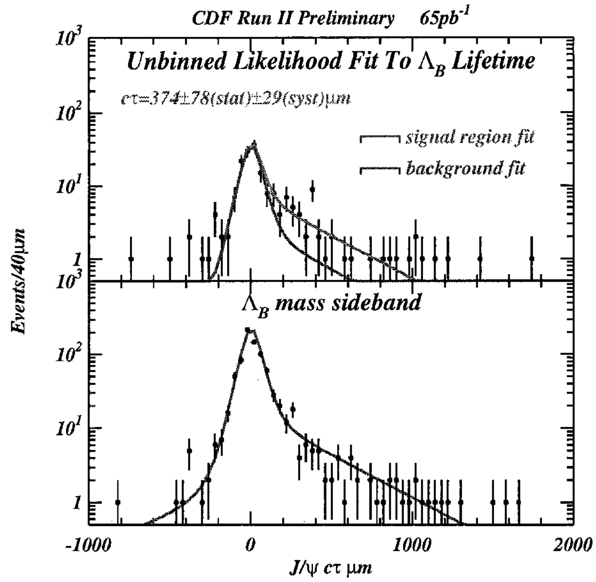

FIGURE 4. Proper time distribution for $J/\psi\Lambda$ combinations where $J/\psi \to \mu^+\mu^-$ is used to trigger the event, and $Lambda \to p\pi^-$.

THE RARE DECAYS $B_S \to \mu^+\mu^-$ AND $D^0 \to \mu^+\mu^-$

Using data selected with the dimuon trigger, CDF has searched for the flavor-changing neutral current (FCNC) decay $B_s^0 \to \mu^+\mu^-$. After applying optimized selection criteria, one event remained in the B_s search window (Fig. 5), yeilding an improved upper limit on the branching fraction of 9.5×10^{-7} (1.2×10^{-6}) at the 90% (95%) confidence level. This is more than a factor of 2 improvement over the previous limit produced by CDF in Run I.

An upper limit on the branching fraction of $B_d^0 \to \mu^+\mu^-$ is derived simultaneously yielding values of 2.5×10^{-7} and 3.1×10^{-7} at the 90% and 95% confidence levels, respectively.

Data selected with the displaced track trigger were used to improve the limit on the branching fraction of the FCNC decay $D^0 \to \mu^+\mu^-$. This search begins by reconstructing a clean sample of the kinematically similar $D^0 \to \pi^+\pi^-$ decays (Fig. 6), then using muon identification to select $D^0 \to \mu^+\mu^-$candidates. The $D^0 \to \pi^+\pi^-$ decays serve also as the normalization. A new upper limit of 2.5×10^{-6} at the 90% confidence level is derived from zero candidates in the search window, and is almost a factor of 2 better than the previous limit[3]. Additional details about rare decay searches at CDF are available in the talk of C.J. Lin[5].

OBSERVATION OF $X(3872)$

In the summer of 2003 BELLE reported the observation in B decays of a new state of narrow width dubbed the $X(3872)$[6]. The state is observed in the decay chain $B \to XK \to J/\psi\pi^+\pi^-K$ with a mass close to $3872\,\mathrm{MeV}/c^2$. At the Tevatron, this state could be produced in B decays, or directly in $\bar{p}p$ collisions. Using $J/\psi \to \mu^+\mu^-$ triggered data, CDF observed a signal in the $J/\psi\pi^+\pi^-$ final state (Fig. 7)[7].

The BELLE collaboration reported that the decay favors high $\pi^+\pi^-$ invariant mass. To verify this observation, we looked at the events with $\pi^+\pi^-$ invariant mass greater than $500\,\mathrm{MeV}/c^2$, and see a number of signal events consistent with the case of no invariant mass requirement (Fig. 8), but sitting on about half as many background events. The significance of the signal is large, in excess of 10 standard deviations.

The nature of this state is a bit of a mystery. The

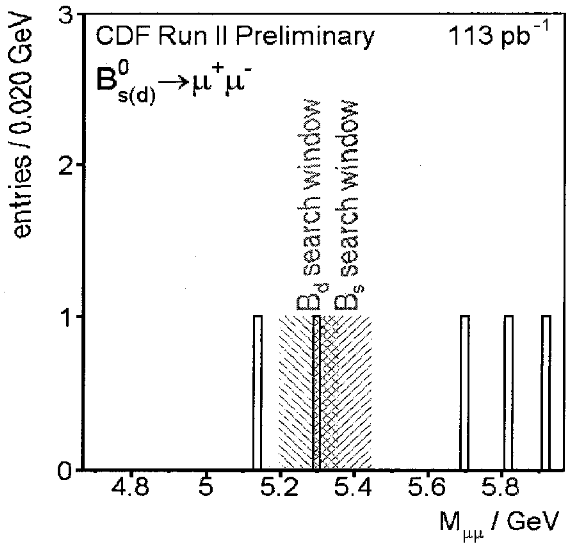

FIGURE 5. The invariant mass distribution for $\mu^+\mu^-$ combinations in the B_d and B_s mass regions.

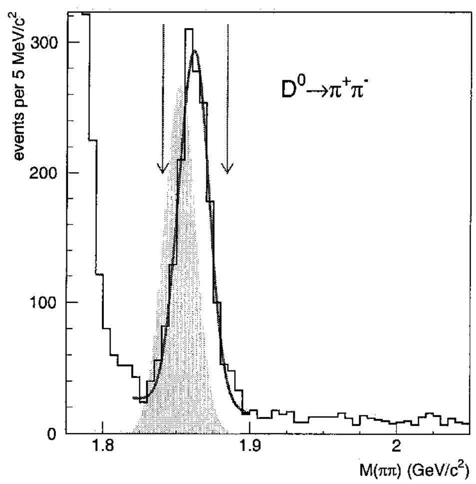

FIGURE 6. The invariant mass distribution for the D^* tagged $D^0 \to \pi^+\pi^-$ candidates. To derive the limit on $D^0 \to \mu^+\mu^-$, these events were searched for cases where both tracks penetrate into the muon detector. The shaded gaussian shows how the invariant mass is shifted when $D^0 \to \pi^+\pi^-$ is reconstructed as $D^0 \to \mu^+\mu^-$.

leading alternatives are (1) a $\bar{c}c$ state, probably the $1\,^3D_2$, or (2) a D^*D molecule. The second alternative is possible as the observed mass is very near the D^*D threshold. Determining the quantum numbers of $X(3872)$ should settle this issue, and the large sample seen at CDF – almost 20 times the number seen at BELLE – can play a role.

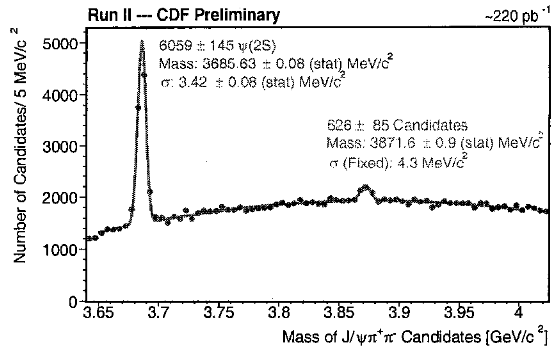

FIGURE 7. Mass distribution for $J/\psi\pi^+\pi^-$ combinations.

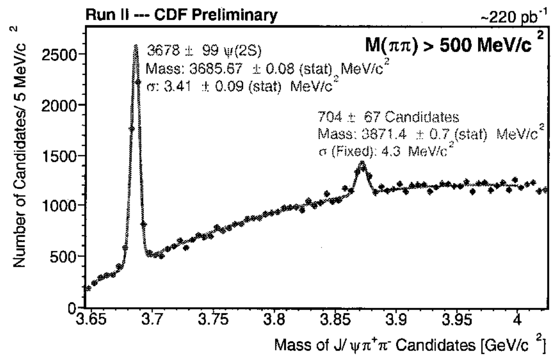

FIGURE 8. Invariant mass distribution for $J/\psi\pi^+\pi^-$ combinations for candidates where the $\pi^+\pi^-$ invariant mass exceeds $500\,\mathrm{MeV}/c^2$.

HADRONIC B DECAYS

The displaced track trigger selects a sample enriched in heavy quark decays. The trigger requires an event to have two oppositely-charged tracks of $p_T > 2.0\,\mathrm{GeV}/c$ with large impact parameter to the beam line, between $120\,\mu$m and $1000\,\mu$m. Further requirements are imposed to reject backgrounds and keep the overall trigger rate within a suitable range. Fully reconstructable decays are important for CP and mixing studies where good proper time resolution is needed. The signals reported here represent our initial attempts to reconstruct fully hadronic decays. We are still learning how to fully exploit the capabilities of the detector to extract physics signals in these data.

$B^0_{d,s} \to h^+h'^-$ Decays

The decays $B^0_d \to \pi^+\pi^-$, $B^0_d \to K^\pm\pi^\mp$, $B^0_s \to K^\pm\pi^\mp$, and $B^0_s \to K^+K^-$ are potential modes for CP measurements by CDF. Although the branching fractions are small, the final state has two high-p_T tracks that are relatively efficient for the displaced-track trigger. However, the invariant mass distributions overlap such that kinematics alone is insufficient to differentiate between the possible mass assignments, as shown in Figure 9. We statistically separate the modes with a combination of invariant mass, decay kinematics, and dE/dx particle identification.

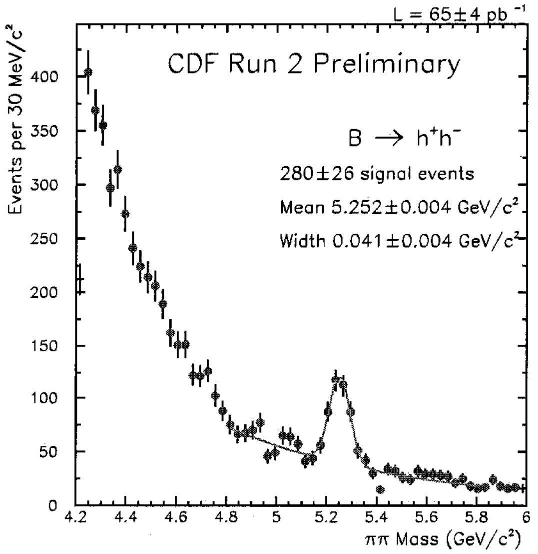

FIGURE 9. The $\pi^+\pi^-$ invariant mass distribution for events selected by the displaced track trigger.

Based on the derived fractions we find the ratio of branching ratios

$$\frac{\mathscr{B}(B_d \to \pi^+\pi^-)}{\mathscr{B}(B_d \to K^\pm\pi^\mp)} = 0.26 \pm 0.15 \pm 0.055\,,$$

and the CP asymmetry

$$\begin{aligned} A_{CP} &= \frac{N(\bar{B}^0_d \to K^-\pi^+) - N(B^0_d \to K^+\pi^-)}{N(\bar{B}^0_d \to K^-\pi^+) + N(B^0_d \to K^+\pi^-)} \\ &= 0.02 \pm 0.15 \pm 0.017\,. \end{aligned}$$

We report the first observation of $B_s \to K^+K^-$, and measured the ratio of branching ratios

$$\frac{\mathscr{B}(B_s \to K^+K^-)}{\mathscr{B}(B_d \to \pi^+\pi^-)} = 2.71 \pm 0.73 \pm 0.35 \pm 0.81\,,$$

where the systematic error on f_s/f_d is included.

$B^0_d \to D^-\pi^+$ and $B^0_s \to D^-_s\pi^+$ Decays

Modes with more final state particles present different reconstruction challenges, and more complex backgrounds that can affect signal extraction. The modes $B^0_d \to D^-\pi^+$ and $B^0_s \to D^-_s\pi^+$ serve as good examples, and $B^0_s \to D^-_s\pi^+$ with its flavor-tagged final state is one of the modes that will be used to observe B_s mixing.

The $D^-\pi^+$ and $D^-_s\pi^+$ invariant mass distributions for data are shown in Figures 10 and 12. The distributions have a complex, multi-peaked structure below the B_d or B_s mass, respectively. Since these data are selected by the diplaced-track trigger, most of the minimum bias combinatoric background is removed and what remains comes primarily from heavy quark decays. By simulating a variety of related B meson decays with particle misassignments or missing neutrals, we are able to reproduce the peaking backgrounds (Figs. 11 and 13). Allowing the overall normalization of each contribution to vary, we fitted the data distributions for signal, peaking B meson backgrounds, and a smooth background contribution, as shown by the red, dashed curves in Figures 10 and 12.

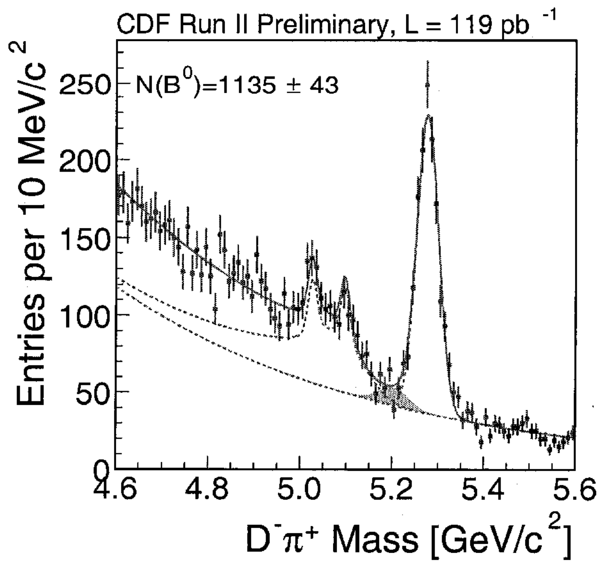

FIGURE 10. The D^-pi^+ invariant mass distribution for events selected by the displaced track trigger.

SUMMARY

Run IIa of the Fermilab Tevatron is in its third year, the CDF experiment is running smoothly, and has collected more than 200 pb^{-1} of physics data being exploited for a wide variety of new results. The CDF collaboration has produced its first three Run II publications: the single best measurement of the mass difference $m(D^+_s) - m(D^+)$ [1]; the first measurement of charm cross sections in high energy hadron collisions [2]; and a new upper limit on the FCNC decay $D^0 \to \mu^+\mu^-$[3]. Papers are in preparation for many other results: observation of a new state $X(3872)$ seen in the $J/\psi\pi^+\pi^-$ final state;

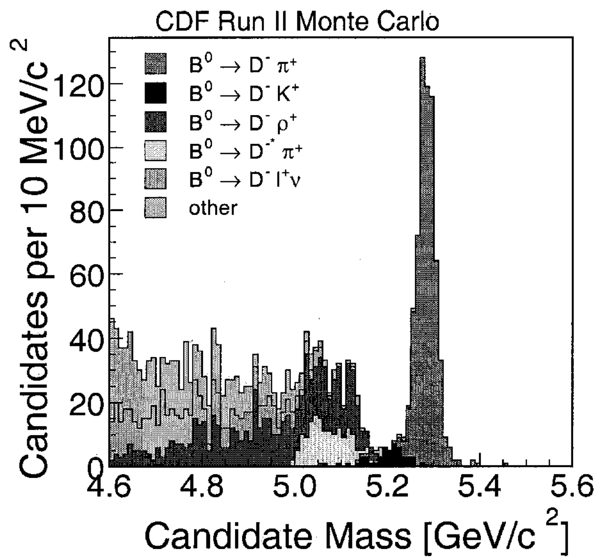

FIGURE 11. The $D^- \pi^+$ invariant mass distribution for Monte Carlo simulation of a number of background modes.

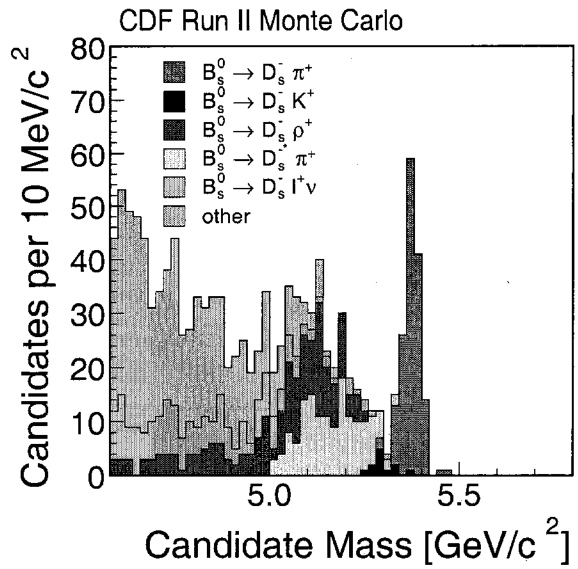

FIGURE 13. The $D_s^- \pi^+$ invariant mass distribution for Monte Carlo simulation of a number of background modes.

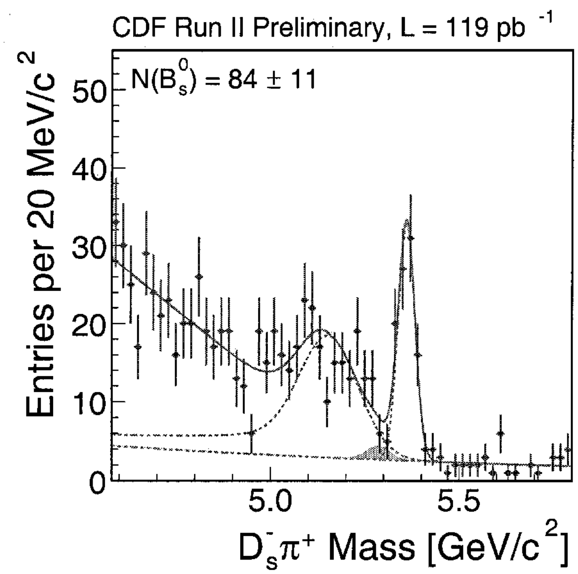

FIGURE 12. The $D_s^- \pi^+$ invariant mass distribution for events selected by the displaced track trigger.

new mass measurements of b hadrons; an improved limit on the FCNC decay $B_s^0 \to \mu^+\mu^-$; the ratio of branching fractions and relative production for $B_s \to D_s^- \pi^+$ and $B_d \to D^- \pi^+$; and the branching fraction of $\Lambda_b \to \Lambda_c \pi$. Measurements of CP violation, and discovery of B_s mixing are major goals of Run II. While these measurements require the high statistics of the full Run II data, work is already underway to develop the tools and techniques for these challenging analyses: b hadron lifetime measurements; and extracting signals in fully-reconstructed, flavor-tagged B_s modes for mixing measurements. Discussions of tagging studies and prospects for mixing and CP violation measurements at CDF where presented by other speakers at the conference [8, 9].

ACKNOWLEDGEMENTS

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